Tevatron Searches for New Phenomena with Leptons

Aspen 2008 Winter Conference

"Revealing the Nature of Electroweak Symmetry Breaking"

13th-19th January 2008 Aspen, CO

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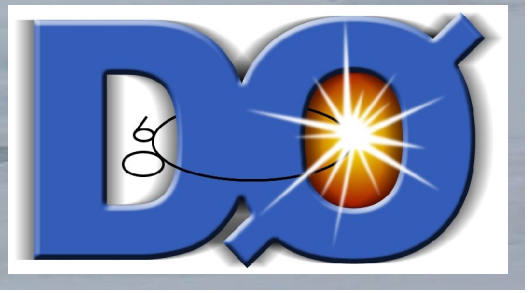
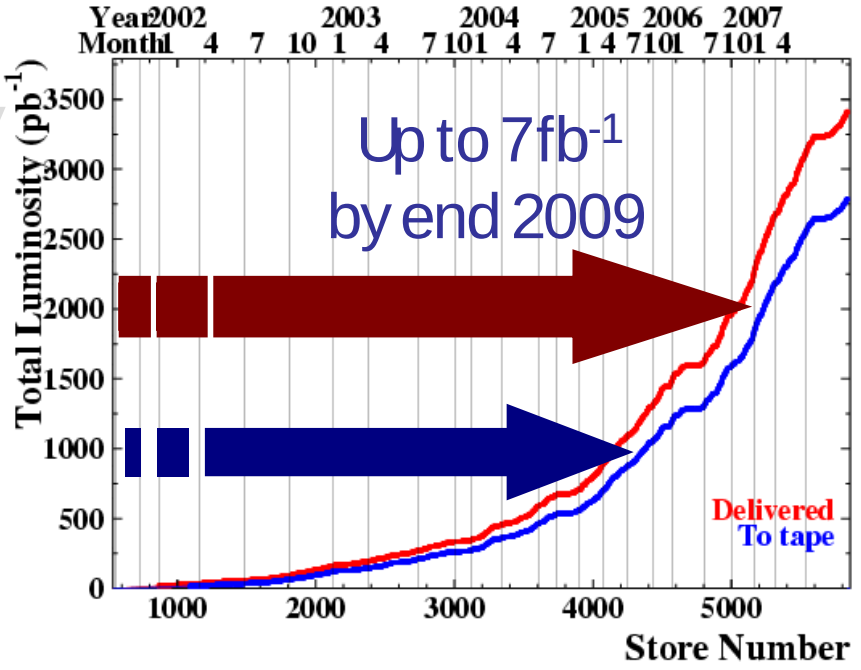


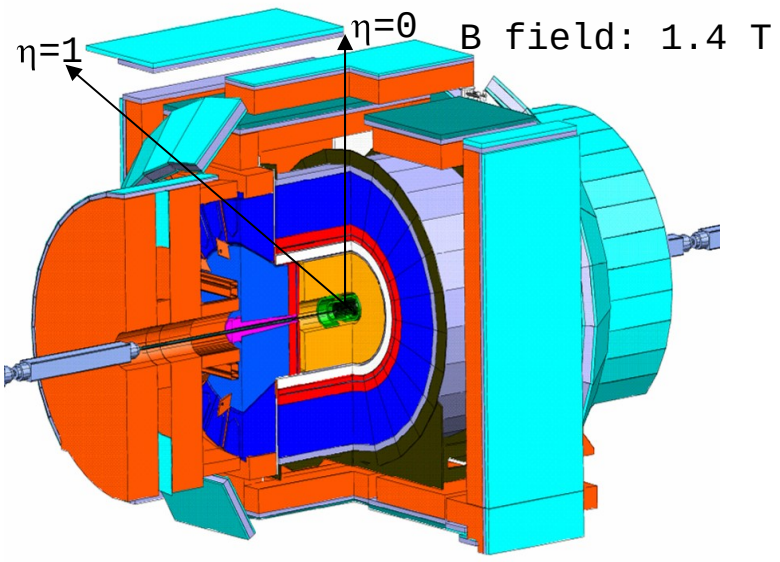
Outline

- Introduction
- Searches for Supersymmetry
  - Chargino and Neutralino
  - Sneutrino
  - Long lived stop
  - $B_s \rightarrow \mu\mu$
- Searches beyond Supersymmetry
  - New gauge bosons
  - Excited electrons
  - Heavy quarks
  - Global search
- Conclusions

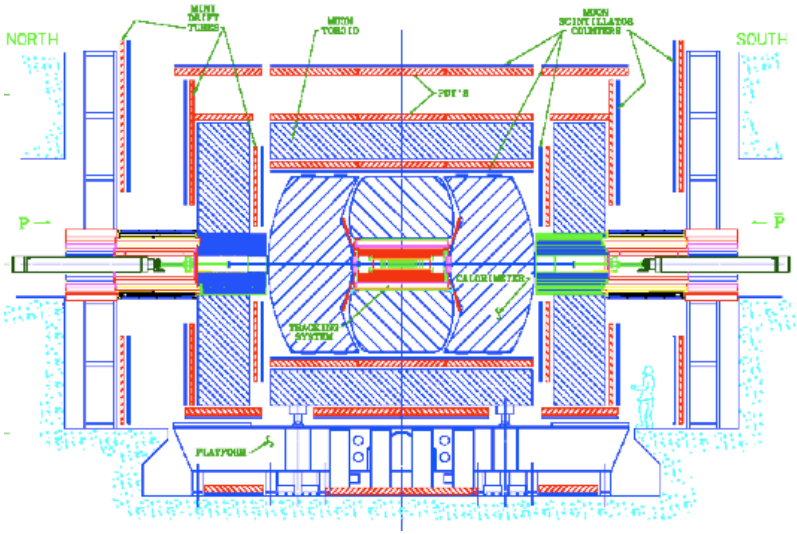


The CDF and D0 detectors

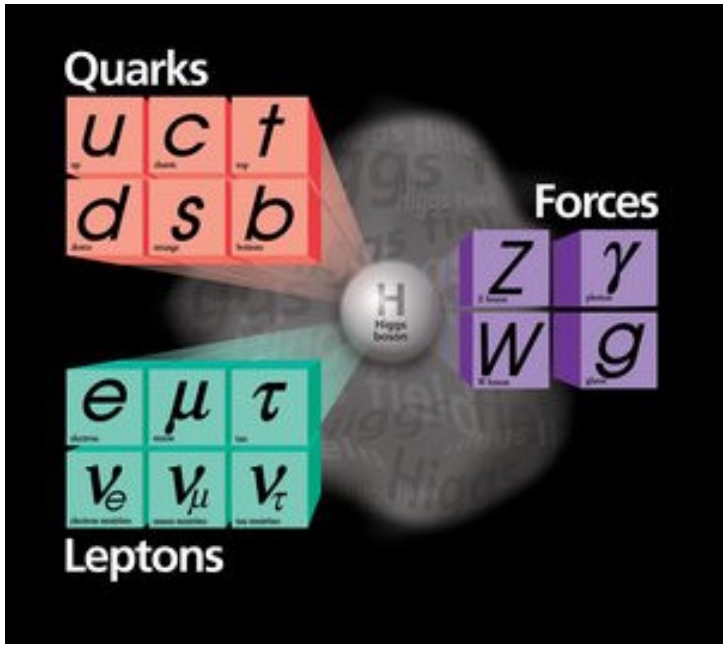
- Central tracking (COT)
  - dE/dx
- Time of flight (TOF)
- Silicon vertex detector
  - Good mass resolution



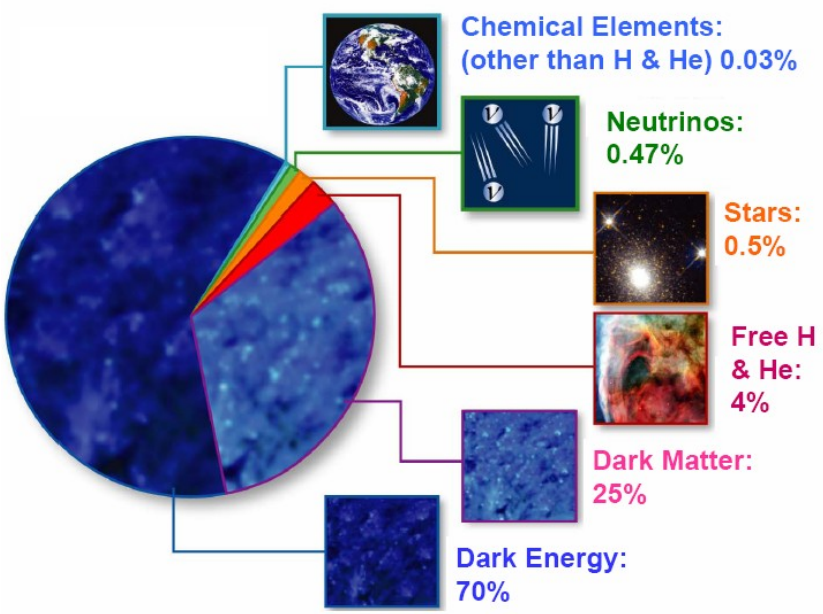
- Muon system
  - Excellent coverage
- Calorimeter
  - Good electron ID



The open questions in the SM



Standard Model predictions confirmed by precision tests up to a few parts per mil



Open questions

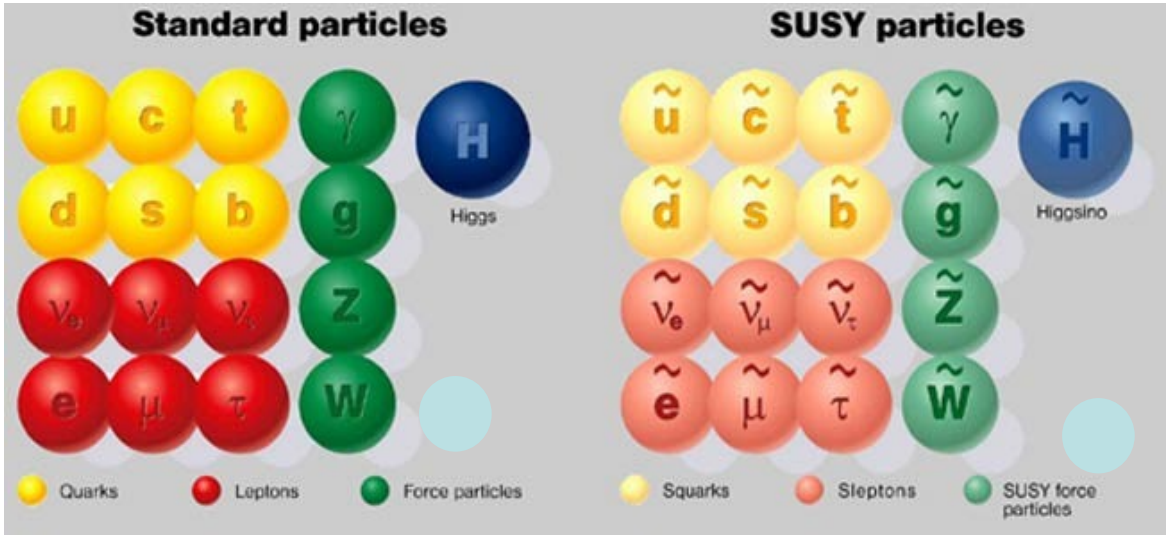
- What is dark matter ?
- Do all the forces unify ?
- How do we include gravity ?
- What's the origin of EWKSB ?

Supersymmetry in 60 sec.

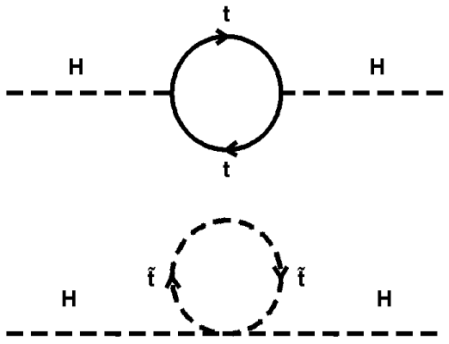
New spin based symmetry

SM fermion (boson)

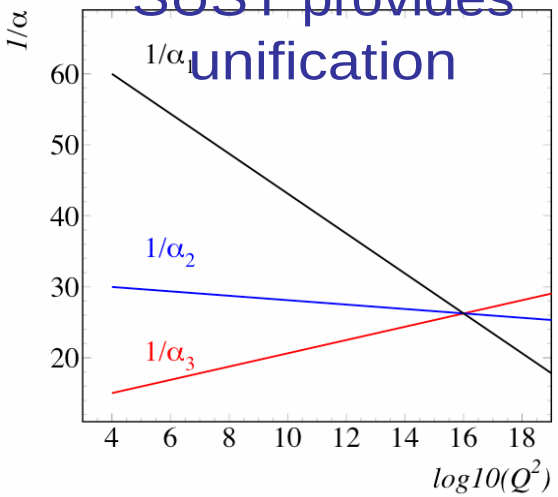
New boson (fermion)



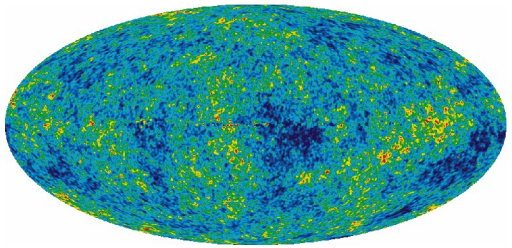
SUSY solves hierarchy problem



SUSY provides $1/\alpha_1$ unification



The LSP is an excellent DM candidate (if R_P conserved)



Sparticle spectrum

No sparticles observed yet !

- SOFT BREAKING

More than 100 free parameters

- MEDIATED BREAKING

mSUGRA

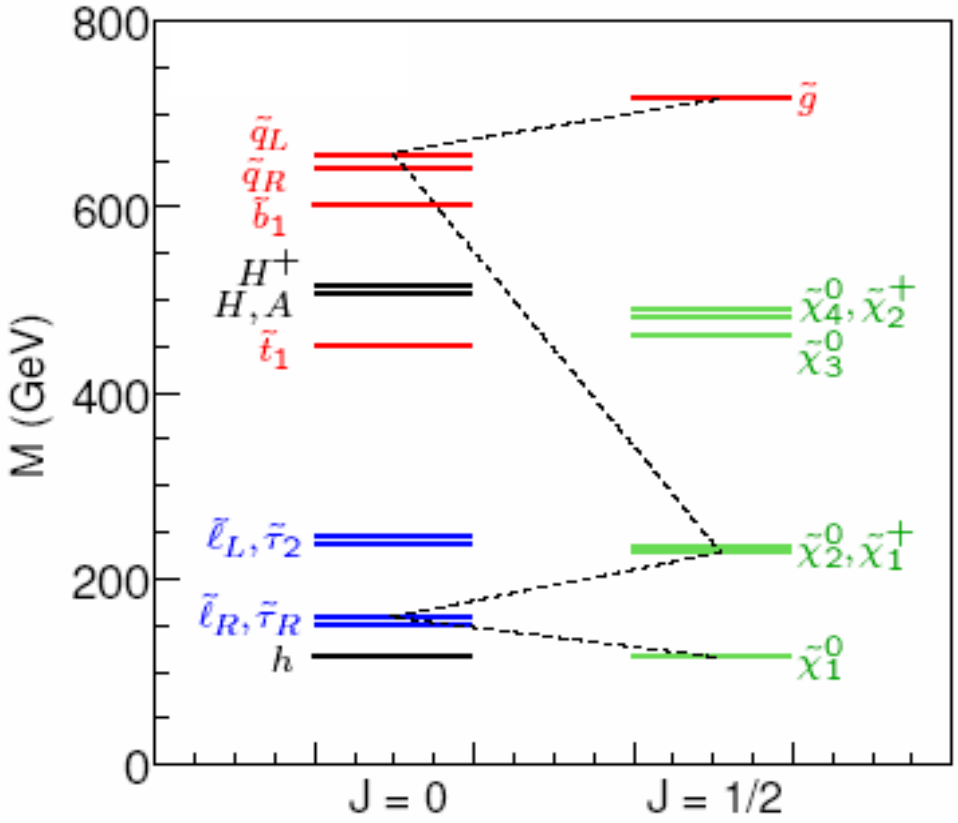
Unified gaugino mass $m_{1/2}$

Unified scalar mass m_0

Ratio of H_1, H_2 vevs tanß

Trilinear coupling A_0

Higgs mass term sgn(μ)



Search for chargino and neutralino

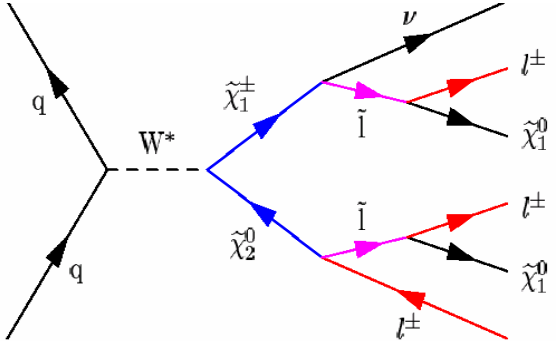
mSUGRA scenario

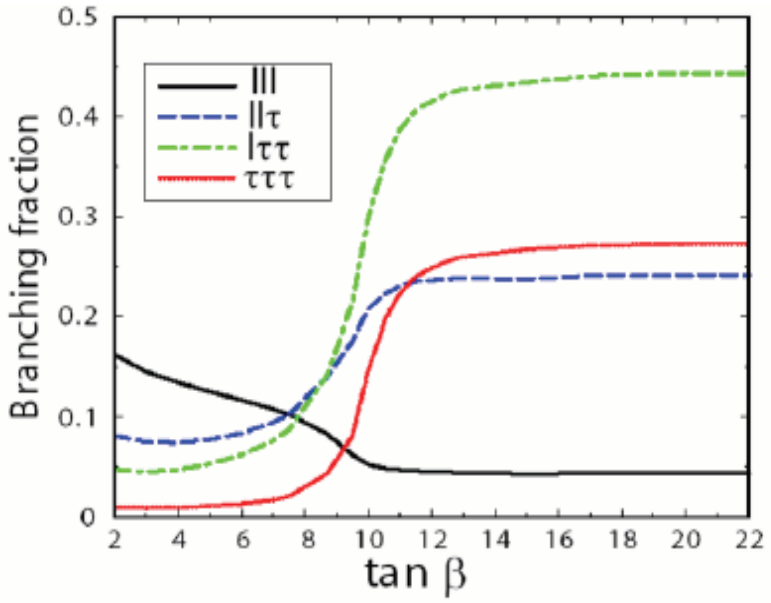
New!
L = 2.0 fb^{-1}

- Pair produced
- Three leptons and large MET

Striking signature at Tevatron !

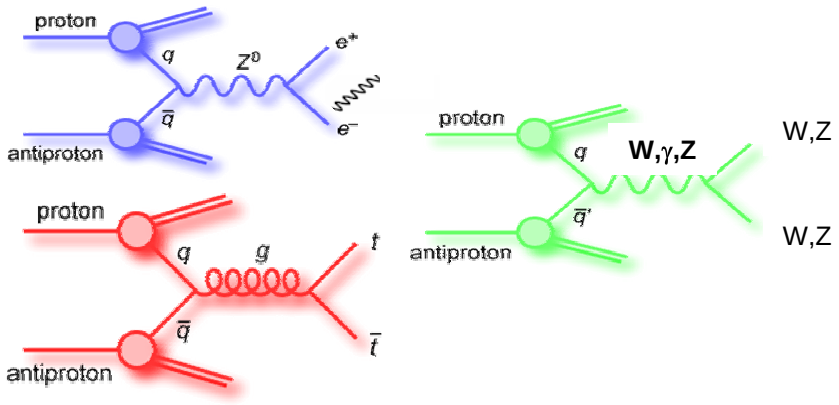
- Unbiased counting experiment
- LEP direct limit $m_\chi > 103.5$ GeV/c^2
  - Leading e/μ $p_T > 15/20$ GeV
  - Tight (t), loose (l) e/μ $p_T > 5$ GeV/c
  - Isolated tracks (T) $p_T > 5$ GeV/c to increase e/μ acceptance and select hadronic τ
    - Isolation: no tracks with $p_T > 0.4$ GeV/c in R=0.4 cone around track

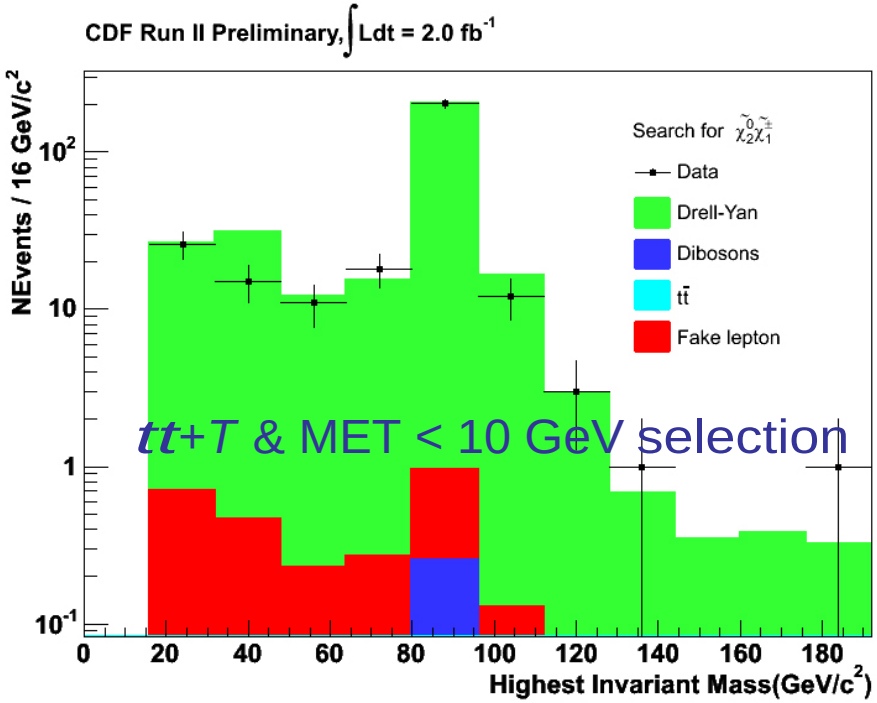




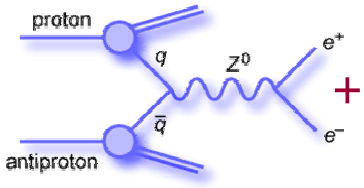
SM Background

- MC driven estimate





- Data driven estimate

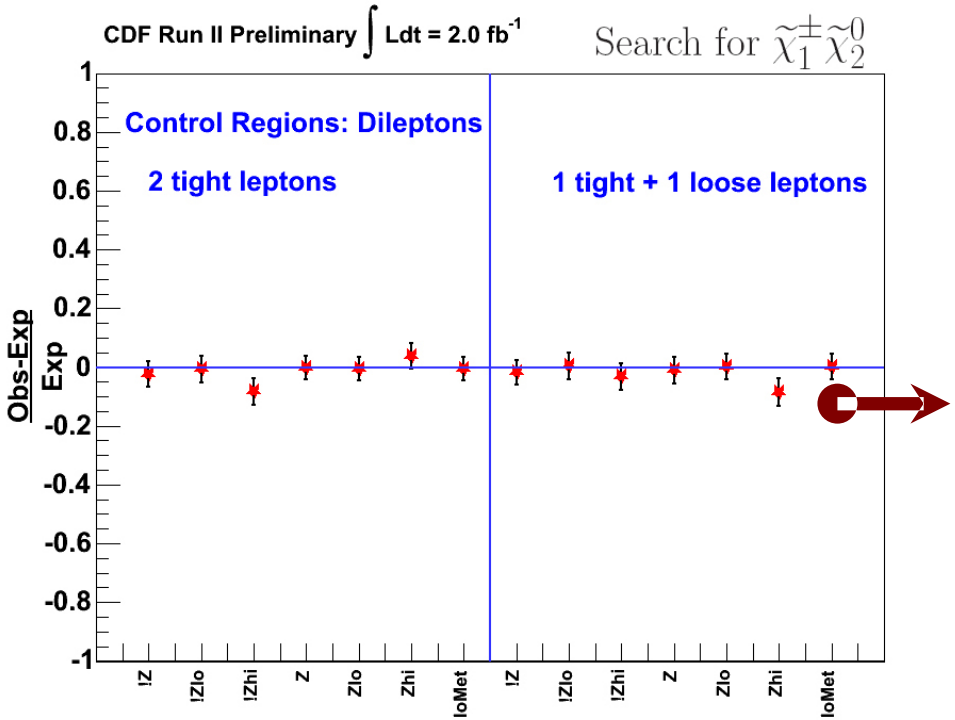


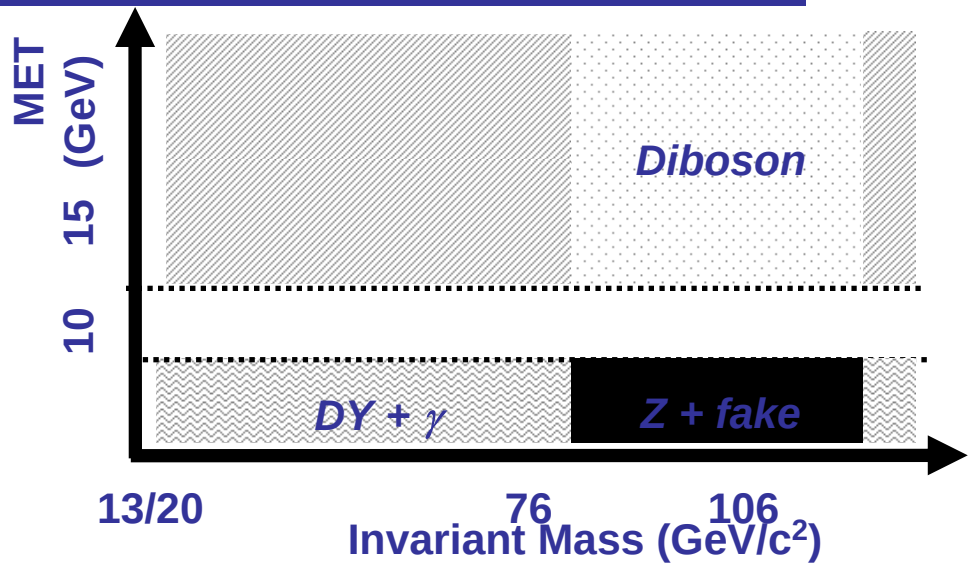
+ hadron (h) misID. as *lepton* or T

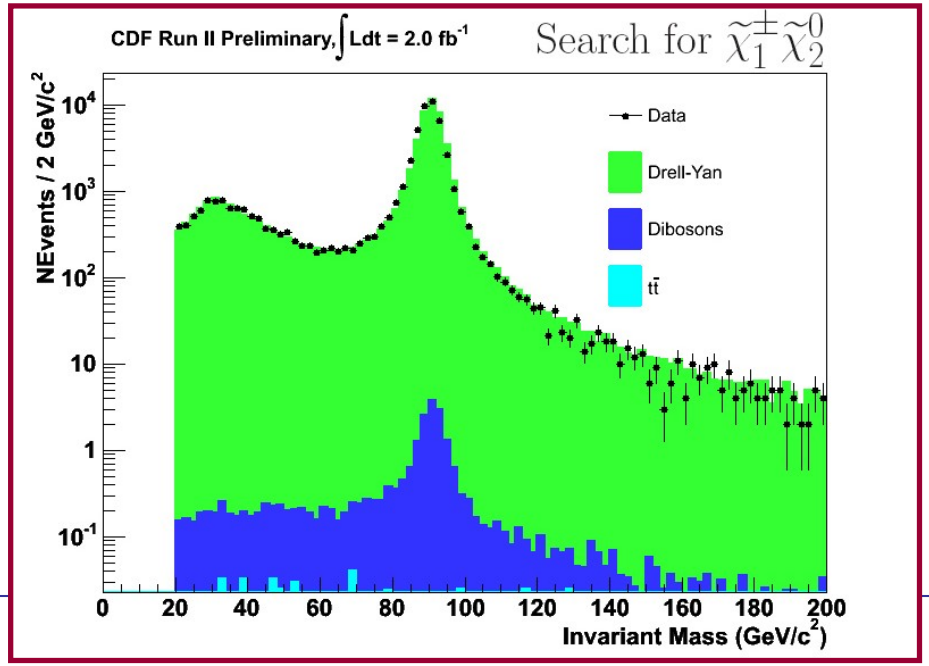
  - Fake rates $P(h \to t,l)$, $P(h \to T)$ measured in data
    - Dilepton + t,l contribution estimated in data
    - Dilepton + T contribution estimated in MC

Data validation

Data analyzed in up to 29 control regions with two or three objects !







Extracting the signal

REQUIREMENTS

- MET > 20 GeV
- $\Delta\varphi_{OS}$ < 2.9(2.8) rad
- Invariant mass cut
- ΣE^{jet}_T < 80 GeV
- N_{jets} < 2

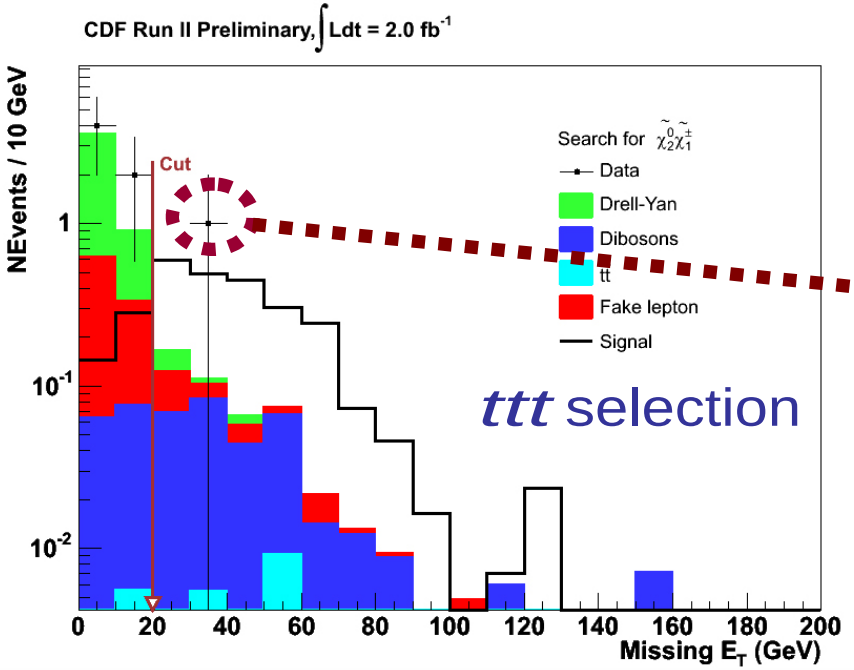
mSUGRA benchmark
$m0=60\ GeV/c^2$
$m_{1/2}=190\ GeV/c^2$
$\tan\beta=3$
$A_0=0$
$\mu>0$

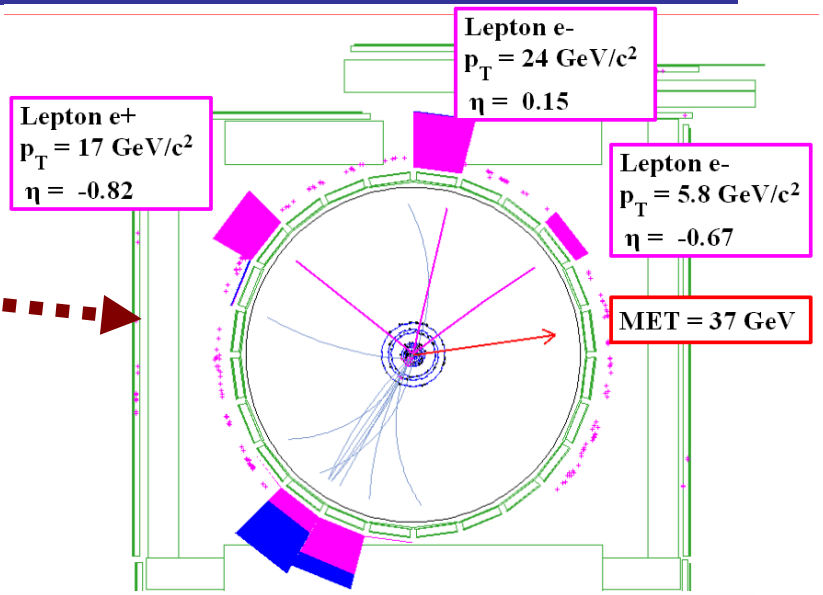
CDF Run II Preliminary L = 2.0 fb^{-1}

Channel	SUSY	Background	Data
ttt	2.3±0.1±0.3	0.5±0.04±0.1	1
ttl	1.6±0.1±0.2	0.3±0.03±0.03	0
tll	0.7±0.1±0.1	0.1±0.02±0.02	0
ttT	4.4±0.2±0.6	3.2±0.5±0.5	4
tlT	2.4±0.1±0.3	2.3±0.5±0.4	2

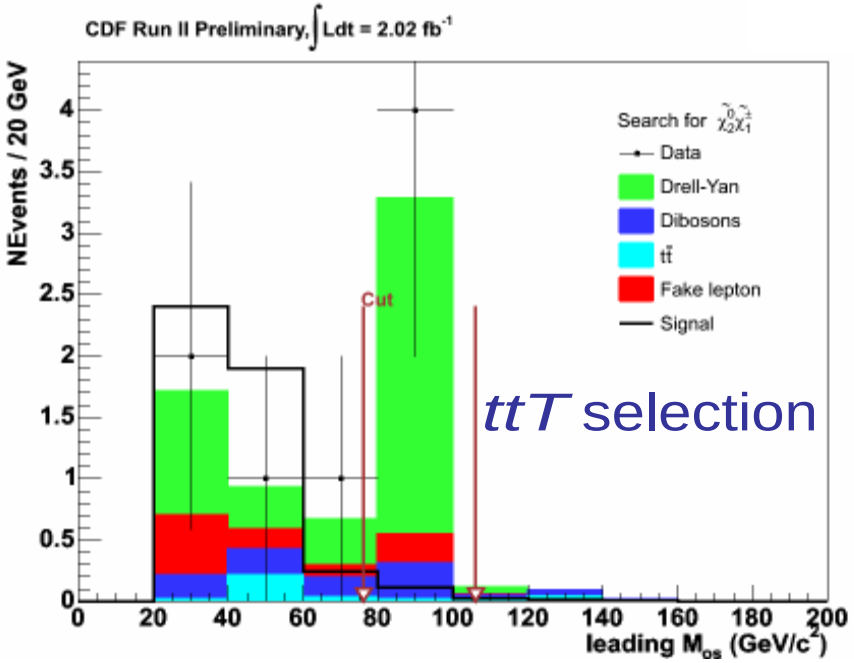
Total SM Background 6 ± 1	7

Observed events



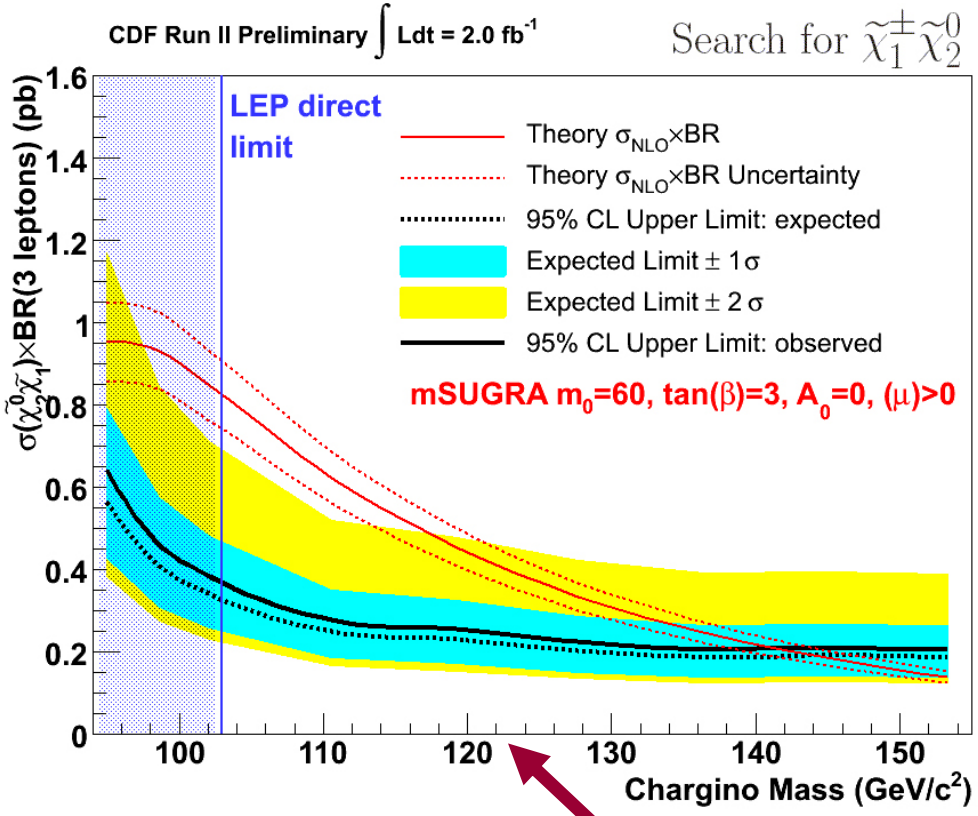


Type	$E_T^{1,2,3}$ (GeV)	M_{OS}^1 (GeV/c^2)	M_{OS}^2 (GeV/c^2)	MET (GeV)	Jet^1E_T (GeV)
$e^-e^+e^-$	24,17,5.8	29	16	37	59
$e^-e^+T^-$	27,9.7,8.5	41	19	28	24
$e^-e^+T^+$	23,9.3,56	70	46	58	18
$\mu^+\mu^-T^-$	34,6.2,9.2	33	28	20	21
$\mu^-\mu^+T^-$	45,21,7.8	29	26	39	41
$\mu^+\mu^-T^+$	23,12.2,6.5	39	18	29	34
$\mu^+\mu^-T^-$	59,70,44	124	58	37	—



Interpretation in mSUGRA scenario

- Expected limit 145 GeV/c^2
- Chargino masses excluded below 140 GeV/c^2



mSUGRA benchmark

First chargino mass limit in mSUGRA scenario at Tevatron !

Chargino and neutralino

- Search performed in $e\mu+\not{T}$, $\mu\mu+\not{T}$ and $\mu^{\pm}\mu^{\pm}$ in L = 1.0 fb^{-1} (Run IIA)
- Search in $ee+\not{T}$ updated to L = 1.7 fb^{-1}
  - Isolated electrons with p_T > 12, 8 GeV/c selected via likelihood
  - Isolated tracks with p_T ($\equiv p^{l3}_T$) > 4 GeV/c
    - Σp_T in hollow cone [R = 0.1-0.4] less than 1 GeV/c
    - Energy in hollow cone [R = 0.2-0.4] less than 3 GeV and less than 60%v(p^{l3}_T)
- Major backgrounds from Z/γ^*, $W+\gamma$,diboson, t-tbar, QCD

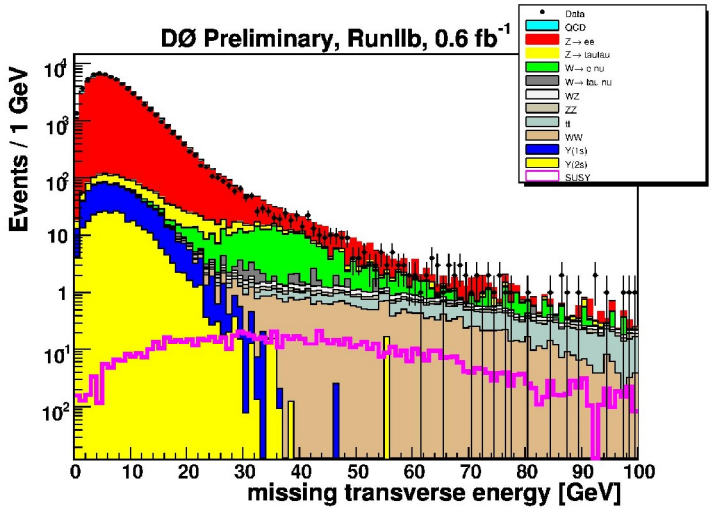
Event selection

$18 < m_{ll} < 60$ GeV/c^2	MET > 22 GeV M_T(e,MET) > 20 GeV Sig(MET) > 8 GeV
$\Delta\phi_{ee} < 2.9$ rad	
M(e,$\not{T}$) < 60 GeV/c^2 and M(e,$\not{T}$)> 120 GeV/c^2 if track not fiducial to calorimeter	MET x p^{l3}_T > 220 GeV/c^2
p^{l3}_T > 7 GeV/c if M_T(e,MET) > 65 GeV	
H_T < 80 GeV	

Results

- Data validation in control regions

mSUGRA with no-slepton mixing
m_0=88-121 GeV/c^2
$m_{1/2}$=182-221 GeV/c^2
tanβ=3
A_0=0
μ>0
Chargino mass 115-150 GeV/c^2

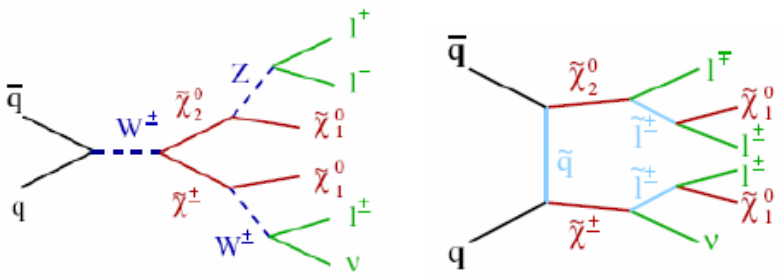


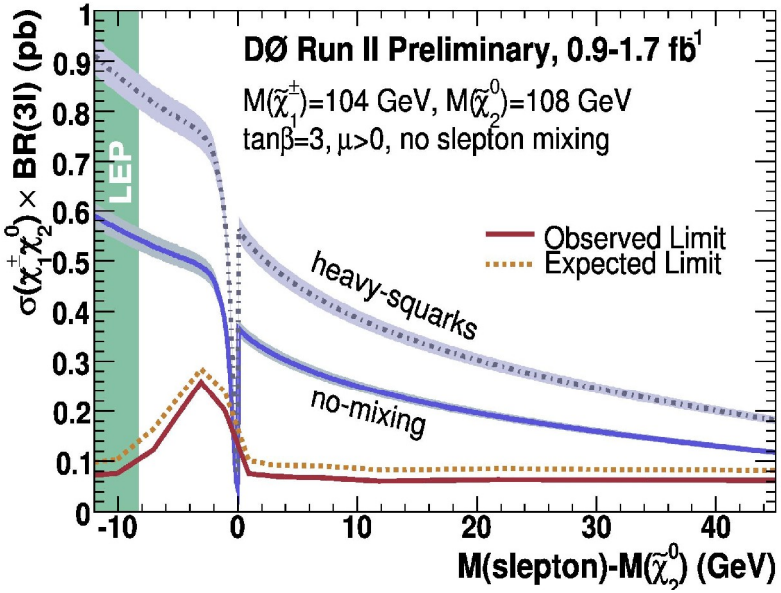
Channel	SUSY	SM Backgr.	Data
ee + $\not\!\!T$ (RunIIb)	0.5-2.1	1.0±0.3±0.1	0
ee + $\not\!\!T$ (RunIIa)	1.7-4.7	0.8±0.7±0.2	0
$\mu\mu$ + $\not\!\!T$ (RunIIa)	0.5-2.5	$0.3\pm^{1.3}_{0.3}\pm0.05$	2
eμ + $\not\!\!T$ (RunIIa)	2.0-2.6	0.9±0.4±0.2	0
$\mu^\pm\mu^\pm$ (RunIIa)	0.6-3.8	1.1±0.4±0.1	1

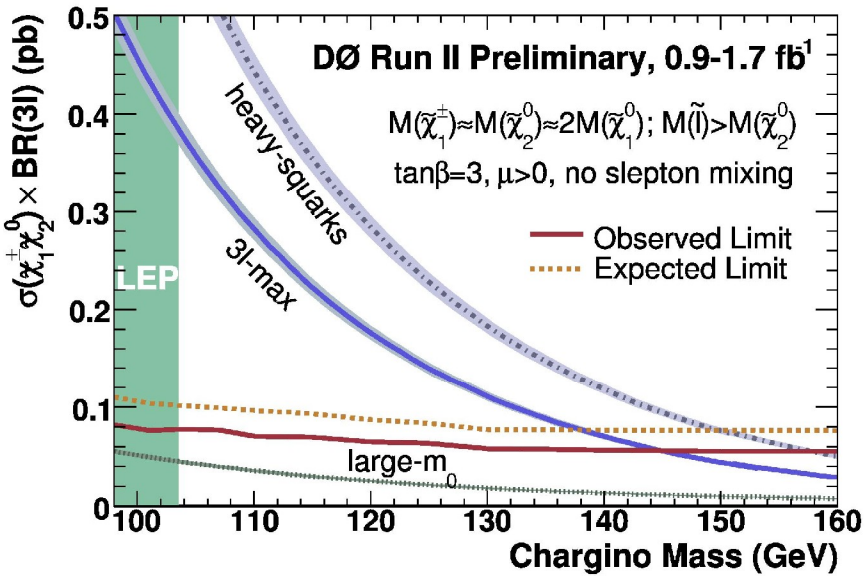
D0 Run II Preliminary L = 0.6-1.0 fb^{-1}

Limits in no-slepton mix scenarios

- Three no-slepton mixing scenarios
  - 3l-max slepton mass ~ chargino mass
  - large m_0 W/Z exchange dominates
  - heavy squarks maximal cross section







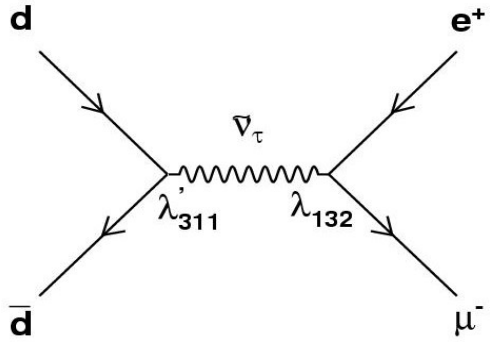
Most stringent mass limits in no-slepton mixing scenarios

Chargino mass excluded below 145 GeV/c^2 in 3l-max model

Tau sneutrino (I)

New!
$L = 1.0\ fb^{-1}$

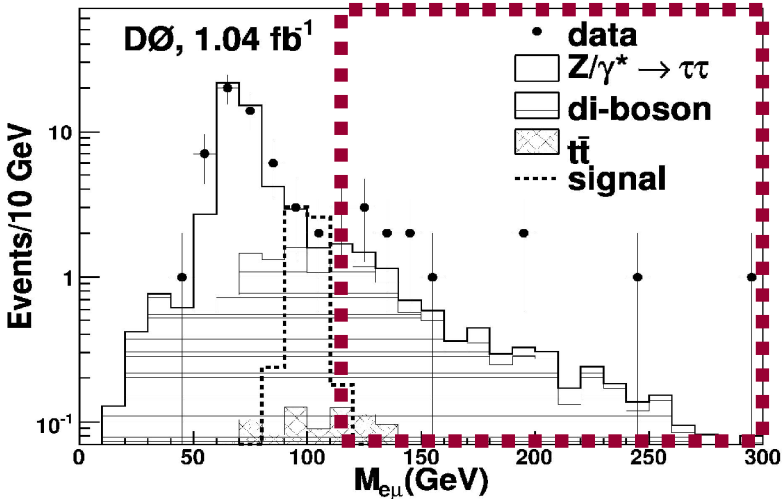
- Lepton number violation observed in the neutral sector
  What if R_P is violated ?
- RPV terms added to the theory $W_{RPV} = \frac{1}{2}\varepsilon_{ab}\lambda_{ijk}L_i^a L_j^b E_k + \varepsilon_{ab}\lambda'_{ijk}L_i^a Q_j^b D_k + \ldots$
- Search for τ-sneutrino
  - "Single coupling dominance"
    - $\lambda'_{311} \neq 0$ and $\lambda_{132} \neq 0$
  - Look for "bump" in $M_{e\mu}$
    - Muon $p_T > 25$ GeV/c
    - Electron $E_T > 30$ GeV
  - SM Background
    - Drell-Yan, diboson, t-tbar

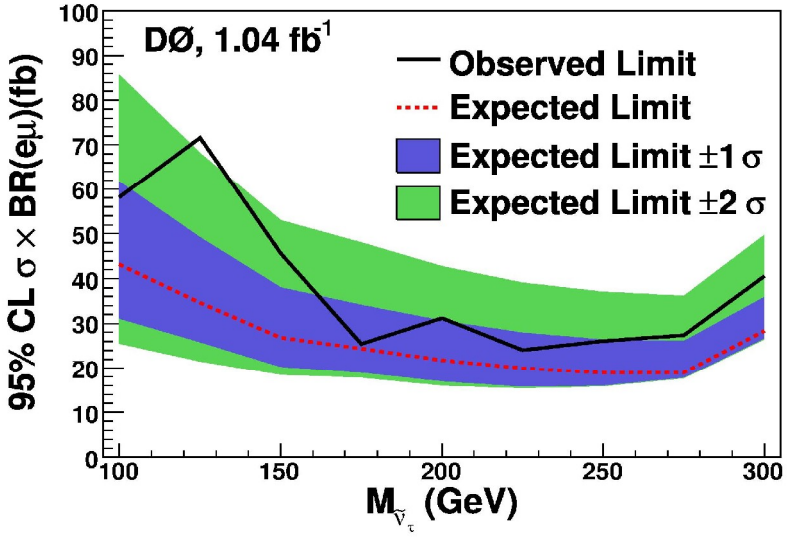


- SM suppressed vetoing
  - events with same flavor leptons
  - events with MET > 15 GeV not aligned with muons or with more than one jet $E_T > 30$ GeV

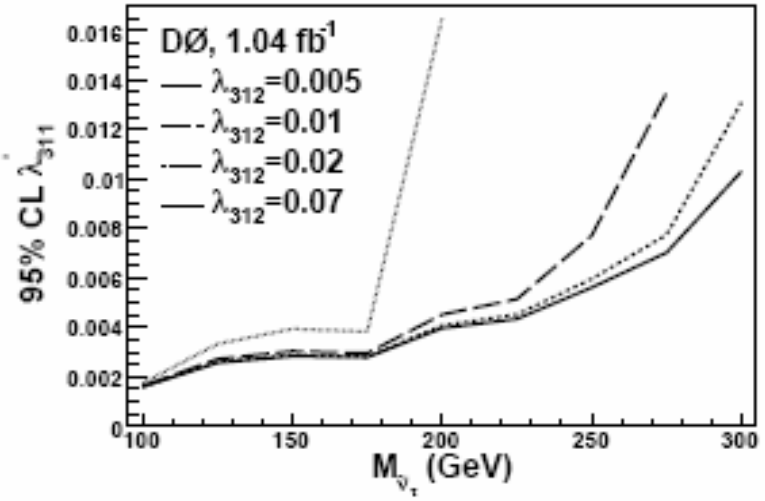
Tau sneutrino (II)

arXiv:0711.3207





SM Backgr.	Data
$Z/\gamma^* \to \tau\tau$	42.9±4.2
WW	13.7±1.5
t-tbar	1.4±0.3
WZ	1.2±0.2
Total Backg.	59.2±5.3
Data	68



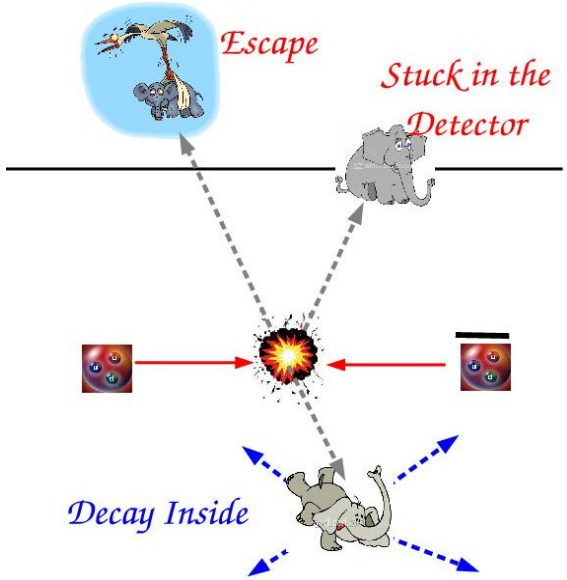
Long lived stop (I)

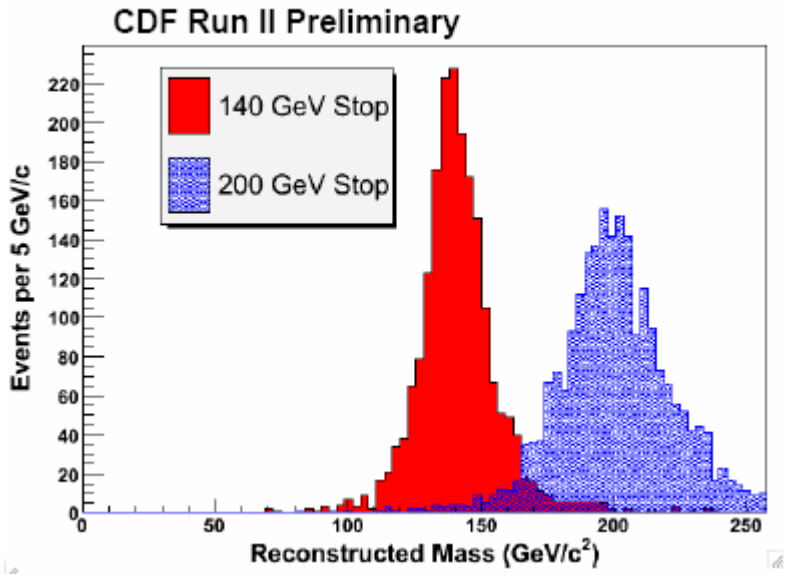
New massive states might be long lived

Search for long lived stop in L= 1.0 fb^{-1}

- Reconstructed as a muon (p_T > 20 GeV/c)
- Delayed hit in TOF and COT
  - Reconstruct β from measured t_0
- Highly ionizing
- Reconstruct mass of candidates

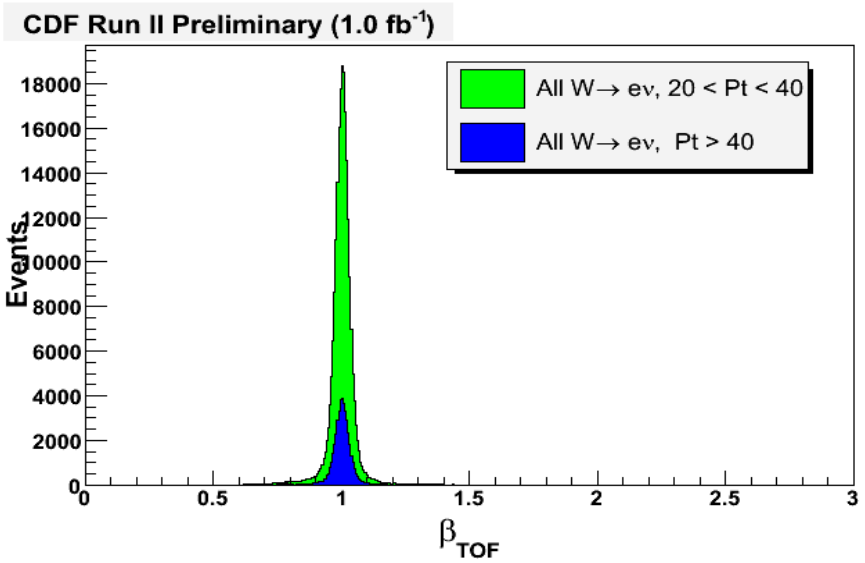
$$m_{TOF} = p\sqrt{1/\beta^2 - 1}$$

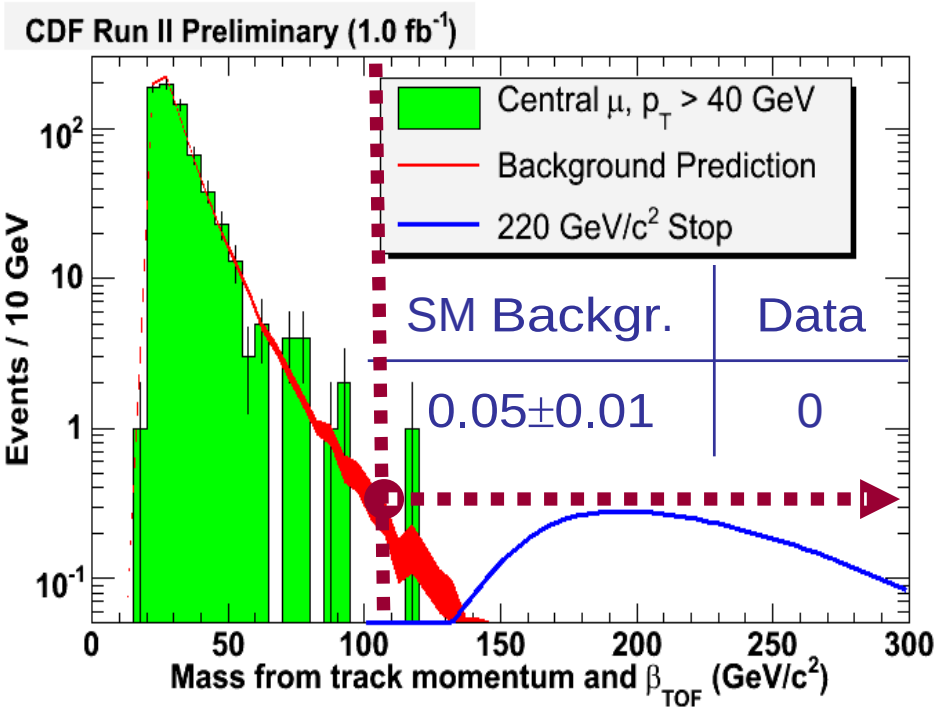


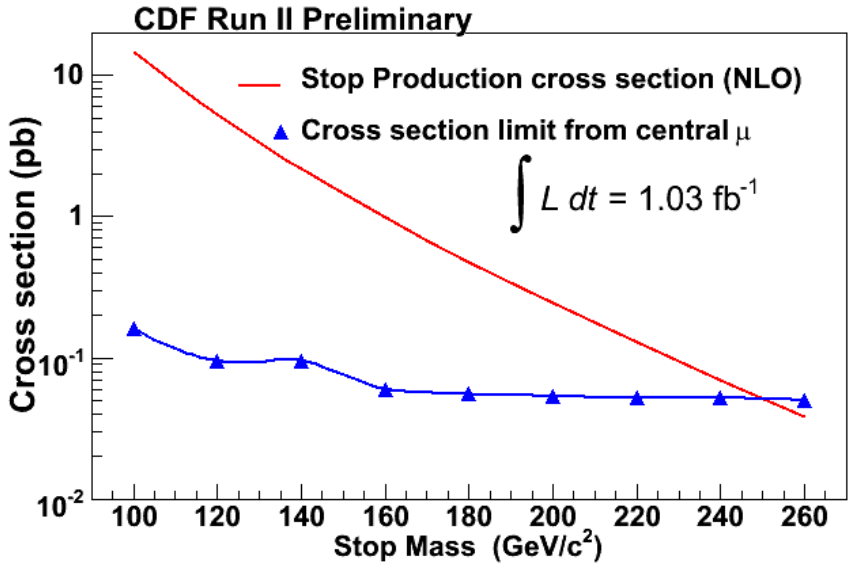


Long lived stop (II)

- Look for a peak in the high mass region (m_{TOF} > 100 GeV/c^2)
- Blind analysis
  - β shape ⊗ momentum extrapolated from control samples

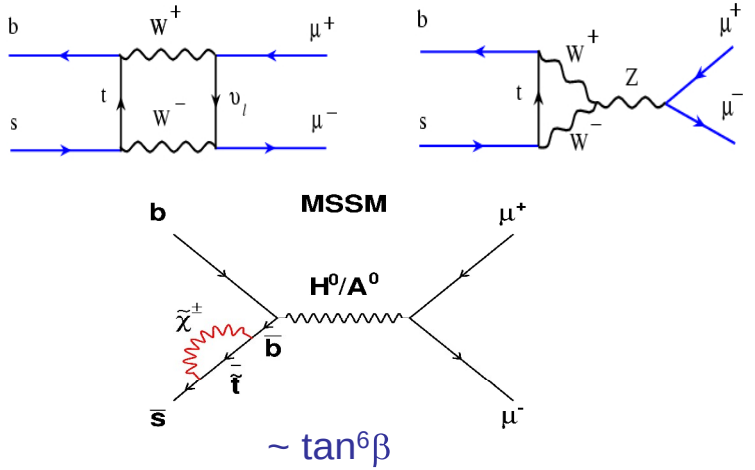


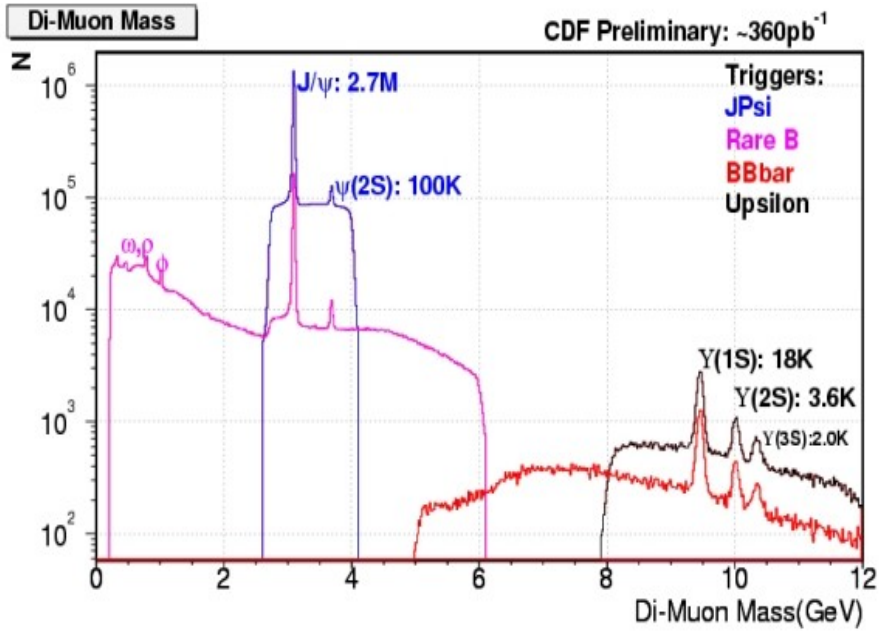




Anomalous $B_s \to \mu\mu$ (I)

- FCNC decays suppressed in the SM
  - $B_s \to \mu\mu = (3.42 \pm 0.54) \cdot 10^{-9} \propto |V_{ts}|$
  - $B_d \to \mu\mu = (1.00 \pm 0.14) \cdot 10^{-10} \propto |V_{td}|$
- BR enhanced in MSSM !





New!
$L = 2.0\ fb^{-1}$

- Look for excess in $M_{\mu\mu}$
  - Muon likelihood ($p_T > 2$ GeV)
  - dE/dx information
  - Signal region

    $5.169 < M_{\mu\mu} < 5.469\ GeV/c^2$

$B_s \rightarrow \mu\mu$ (II)

- Seven discriminating variables in NN
  - 25% improvement
- Normalization to the $B \rightarrow J/\psi K^+$
- Limits set in 3 NN output bins and 5 mass bins

NN	Total Backg.	Data
0.995-1.0	3.5 ± 0.2	3
0.95-0.995	18.0 ± 0.7	21
0.8-0.95	49.5 ± 0.9	44

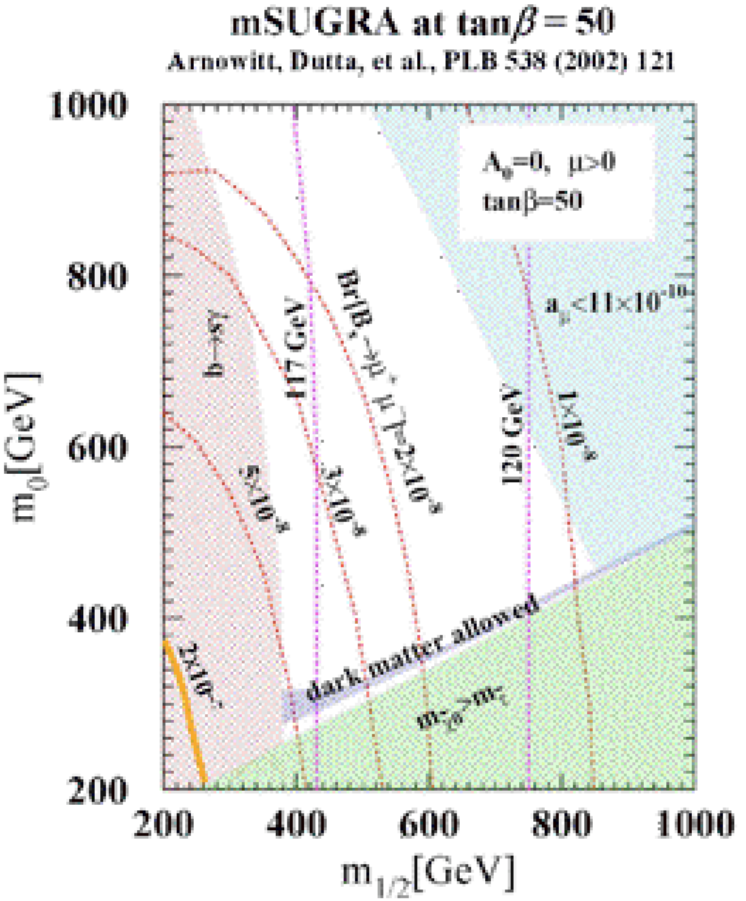
95% C.L. Limits

$BF(B_s \rightarrow \mu^+\mu^-) < 5.8 \times 10^{-8}$

$BF(B_d \rightarrow \mu^+\mu^-) < 1.8 \times 10^{-8}$

1 event in signal like bin

1 in the adjoining bin!



arXiv:0712.1708v1, submitted PRL

What if not SUSY ?

W' (I)

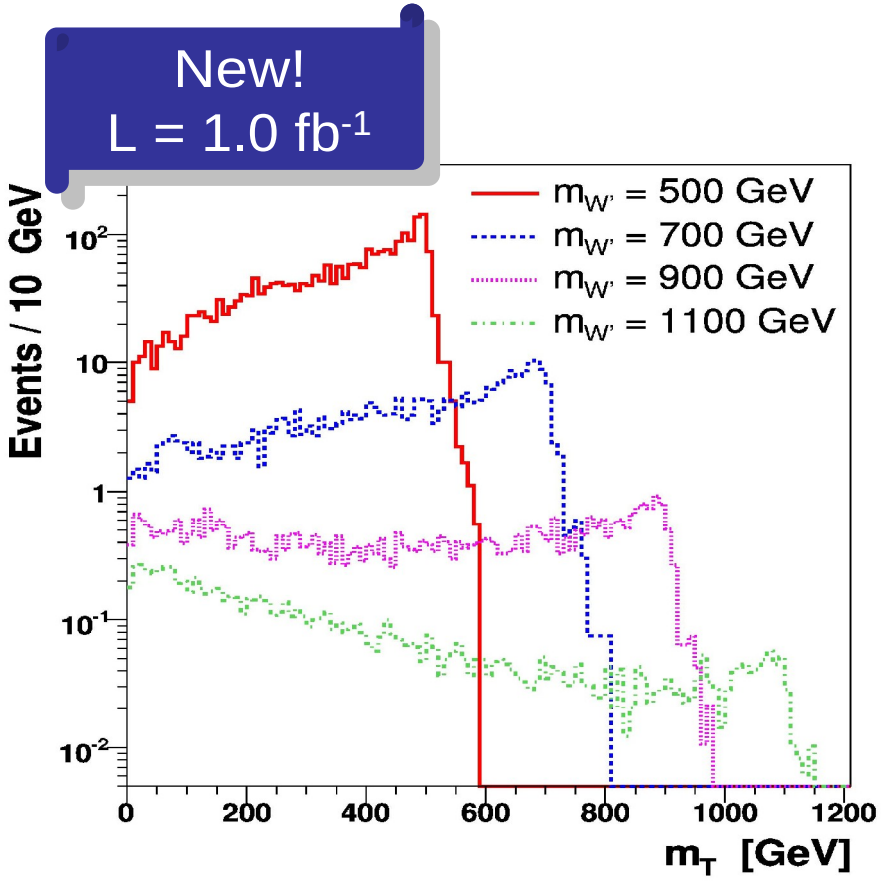
NP predicts existence of new charged heavy vector boson
(Left-right Symmetric models, E6 models, …)

Search for $W' \to e\nu$

- RH or LH
- No mixing, SM couplings, SM CKM
  - W' → WZ suppressed
  - W' → tb allowed
  - Additional generations of fermions assumed to be heavy
- Look for excess in high m_T region

$$M_T = \sqrt{2E_T \cdot MET \cdot (1 - \cos\Delta\phi)}$$

$$\text{with } \Delta\phi = \Delta\phi(\text{electron}, \text{MET})$$

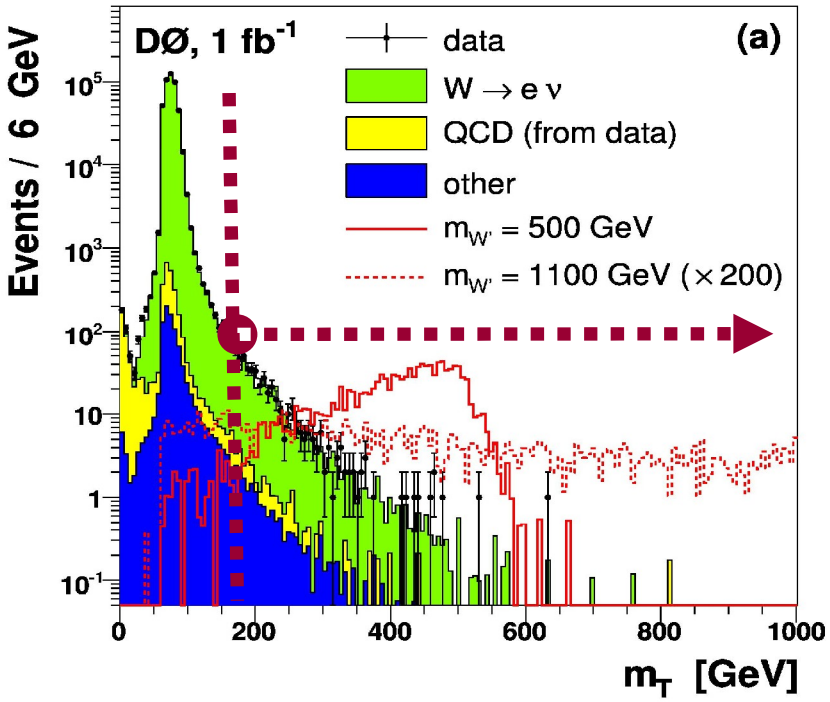


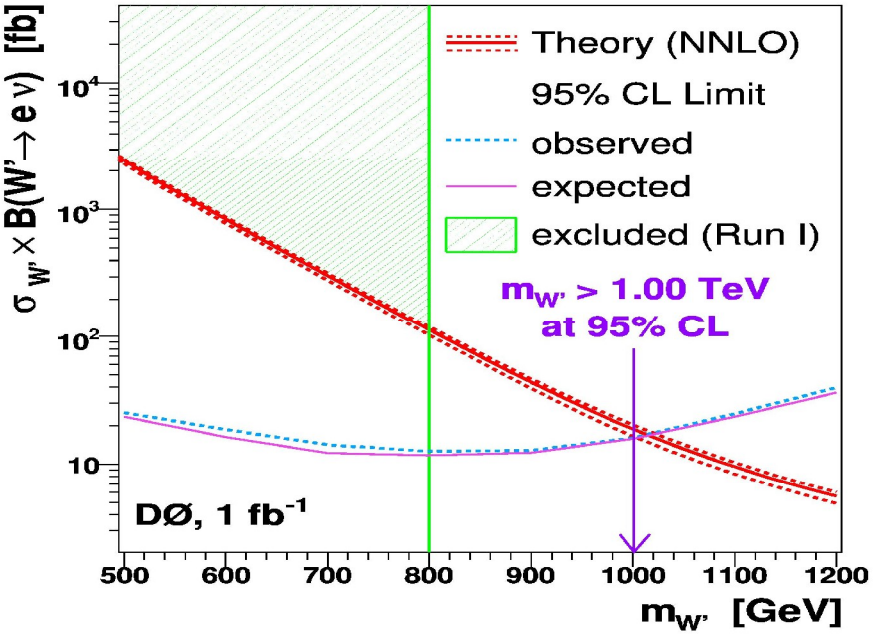
W' (II)

http://arxiv.org/abs/0710.2966

- Neutrino p_T expected to balance electron E_T
  - E^{ele}_T and MET > 30 GeV
  - $0.6 < E^{ele}_T / \text{MET} < 1.4$
- m_T > 140 GeV as "signal" region

W→eν	875 ± 21 ± 90
QCD	27 ± 2 ± 2
others	57 ± 3 ± 4
Total Backg.	959 ± 21 ± 90
Data	967





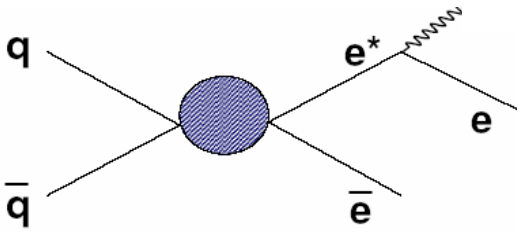
Excited electrons (I)

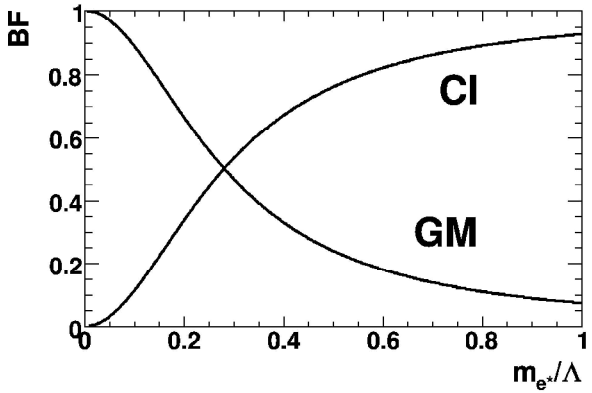
Compositeness can explain the observed mass hierarchy of fermions

New!
$L = 1.0\ fb^{-1}$

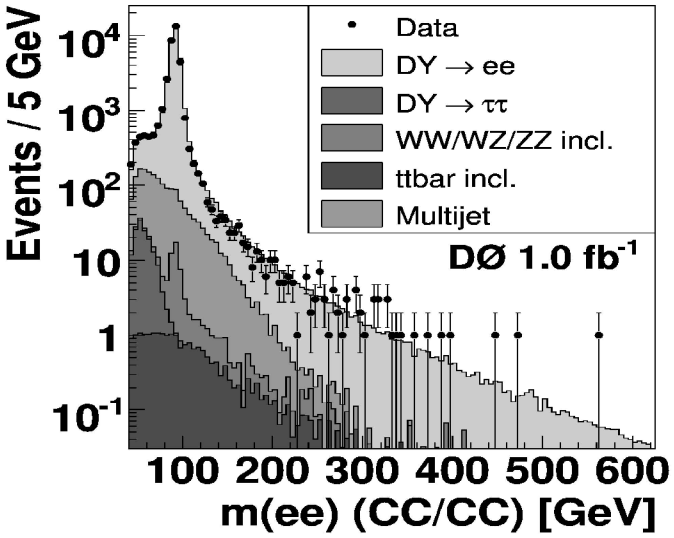
Search for excited electrons

- Production via 4 fermion contact interaction



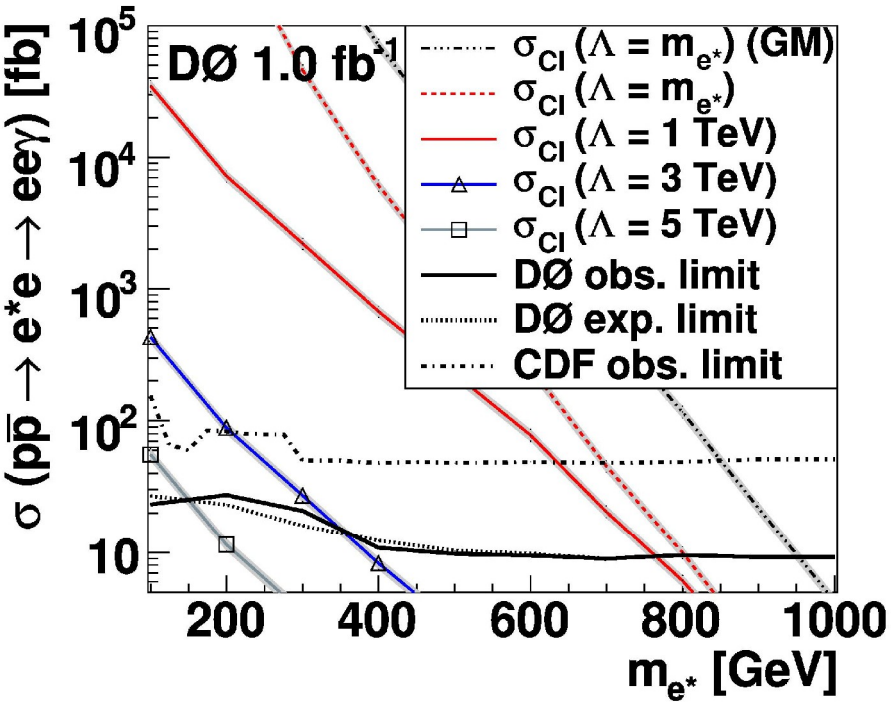


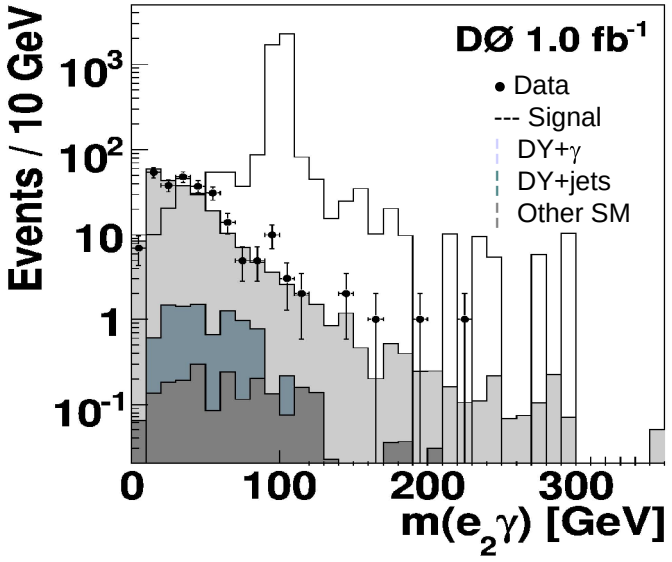
- Events with
  - 2 isolated electrons with $E_T > 25\ (15)$ GeV
  - End cap electrons included ($|\eta| < 2.5$)



Excited electrons (II)

- Isolated photon requirement to select signal like events
- Events selection based on optimal
  - $\Delta R_{e\gamma}$ and $M_{e\gamma}$
- Look for deviations in the spectrum





For $m_{e^*} = 100$ GeV/c^2
SM = 0.3±0.1±0.03
Data = 0
No excess over the SM predictions !

$M_{e^*} > 756$ GeV/c^2
for $\Lambda = 1$ TeV

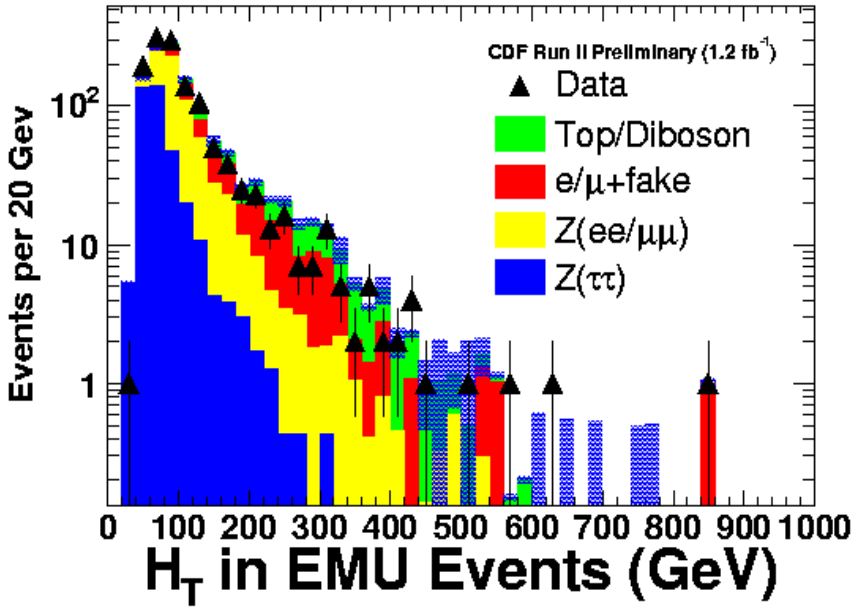
http://arxiv.org/abs/0801.0877

Heavy squarks (I)

New heavy quarks predicted in SO(10) and E(6) models

Search for heavy quarks in L= 1.2 fb^{-1}

- Decaying into EWK bosons and light quarks
- Generic signatures with 2 high p_T leptons (and MET > 20 GeV)
- Search channels
  - $e\mu$, $l\tau$ + MET , LS, ll (SF, OS) + MET
  - electrons and taus selected with likelihood
- Signal region
  - 2 jets with E_T > 15 GeV
  - $H_T = \Sigma$ ID objects $E_T > H_T^{min}$
  - E_T of sub-leading jet > E_T^{min}



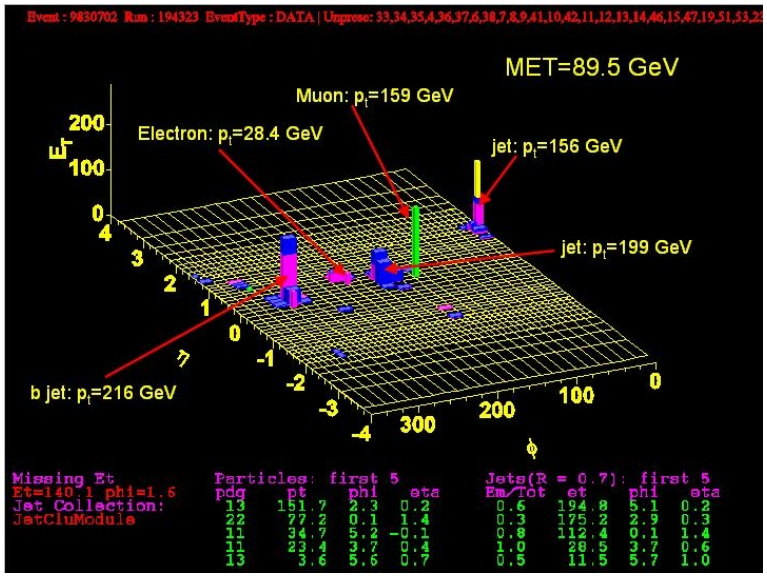
E_T^{ele} > 20, 12 GeV; p_T^{μ} > 20, 12 GeV/c; τ p_T > 15 GeV/c

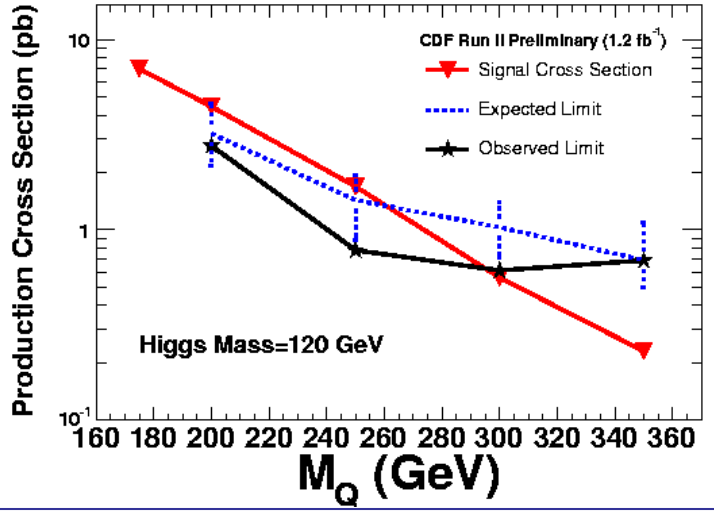
Heavy squarks (II)

Signal Mass (GeV/c^2)	Jet E_T	H_T
200	40	350
250 **	50	400
300	50	450
350	70	550

CDF Run II Preliminary L = 1.2 fb^{-1}

Channel	Backg.	Data	Signal **
eμ	3.3±1.3	3	5.0±0.6
lτ + MET	3.1±1.7	1	5.2±0.3
LS	3.1±2.0	0	1.9±0.3
ll & MET	1.6±0.4	1	2.7±0.4
Total	11.2±4.3	5	14.9±1.4



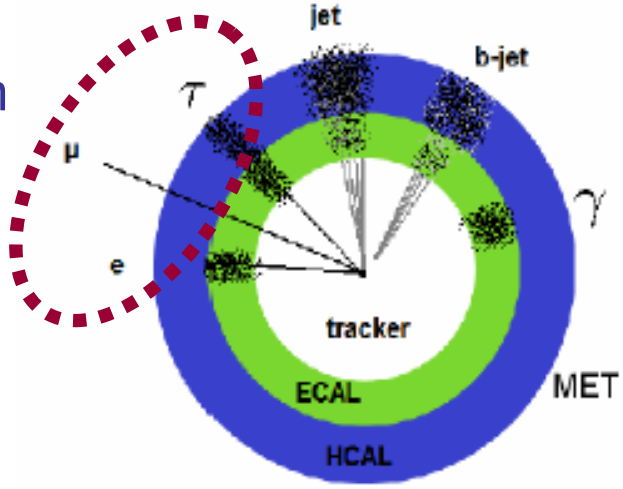


Global Search

Searching globally the high p_T sample ($L = 1.0\ fb^{-1}$)

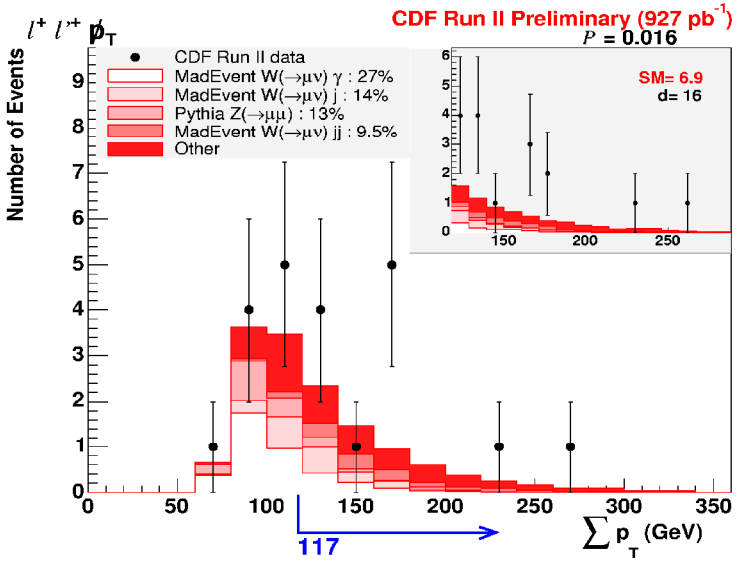
VISTA

- Explored 16,486 kinematical distributions in 344 final states



SLEUTH

- Searched for deviations in the tail of Σp_T



This "global" search considered gross features of data and revealed no new large cross section physics in $1fb^{-1}$

hep-ex/0712.2534; hep-ex/0712.1311

Conclusions

CDF and D0 look for New Physics
in up to 2 fb^{-1} of Tevatron collisions

- Model dependent searches for "known" New Physics
  - SUSY, New Gauge Bosons, Compositeness, ...
- Signature based searching for "unknown" New Physics
- No signs of New Phenomena

  - Stronger constraints!

More data to come in the near future !

http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

BACK-UP SLIDES

Chargino and Neutralino @CDF

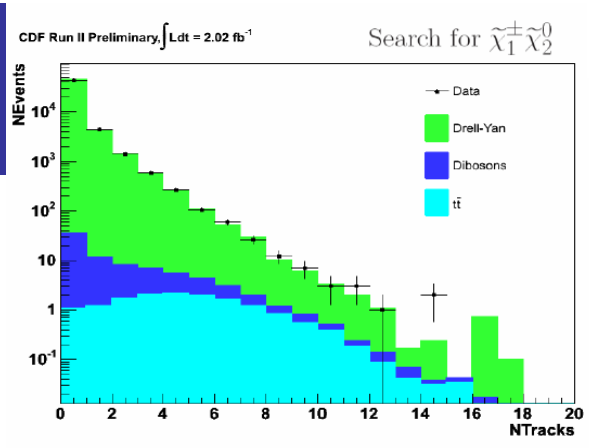


Figure shows the track multiplicity for dilepton events with lepton pair mass 76 < Mass < 106 GeV/c². The tracks have P_T>4 GeVand pass certain quality

pythia--slepmix

m0	m12	BR	mchi+-	m~tau_1	m~e_R
60	162	0.7713	95.04292	92.14055	93.54939
60	164	0.8314	96.76254	92.62837	94.03017
60	166	0.8736	98.59132	93.11570	94.51378
60	168	0.8997	100.35171	93.60207	95.00153
60	170	0.9167	102.08421	94.09568	95.49183
60	172	0.9239	103.51860	94.61205	95.98609
60	174	0.9334	105.28384	95.11501	96.48264
60	176	0.9408	107.10715	95.61946	96.98311
60	178	0.9452	108.76022	96.13360	97.48689
60	180	0.9496	110.55578	96.64372	97.99360
60	182	0.9530	112.33761	97.15668	98.50338
60	184	0.9556	114.10233	97.67310	99.01608
60	186	0.9576	115.86657	98.17817	99.51504
60	188	0.9593	117.66165	98.69778	100.03115
60	**190**	**0.9606**	**119.30085**	**99.22203**	**100.55098**
60	192	0.9622	121.01557	99.70989	101.02874
60	194	0.9620	122.42855	100.25095	101.55453
60	196	0.9627	124.18005	100.78316	102.08308
60	198	0.9632	126.00815	101.31829	102.61389
60	200	0.9634	127.72567	101.85728	103.14762
60	202	0.9634	129.51006	102.40005	103.68315
60	204	0.9635	131.25421	102.94100	104.22074
60	206	0.9635	132.99100	103.48542	104.76160
60	208	0.9630	134.61545	104.03856	105.30602
60	210	0.9627	136.42354	104.58833	105.85223
60	**220**	**0.9601**	**144.87340**	**107.37395**	**108.61687**
60	230	0.9542	153.33261	110.19878	111.41077

Channel/Source	ID (%)	Trig (%)	JES (%)	X-sec (%)	PDF (%)	ISR/FSR (%)	Conv (%)	ITR(nom) (%)	ITR(alt) (%)	Fake (%)
3tight	2.3	0.3	1.5	5.0	1.4	2.3	2.2	-	-	12.2
2tight,1loose	2.5	0.3	1.7	5.9	1.6	2.5	2.1	-	-	8
1tight,2loose	2.2	0.3	3.5	5.0	1.3	2.2	1.8	-	-	10.7
2tight,1Track	1.8	0.2	3.9	2.3	1.5	1.8	-	5.8	6.0	11.6
1tight,1loose,1Track	1.8	0.2	5.2	2.4	1.5	1.8	-	8.6	10.5	9.0
Signal	4	0.5	0.5	10	2	4	-	-	-	-

ID : lepton identification
Trig : trigger efficiency
JES : jet energy scale
Xsec: Process cross section
PDF : parton density functions
ISR/FSR : initial/final state radiation
Conv: conversion scalefactor

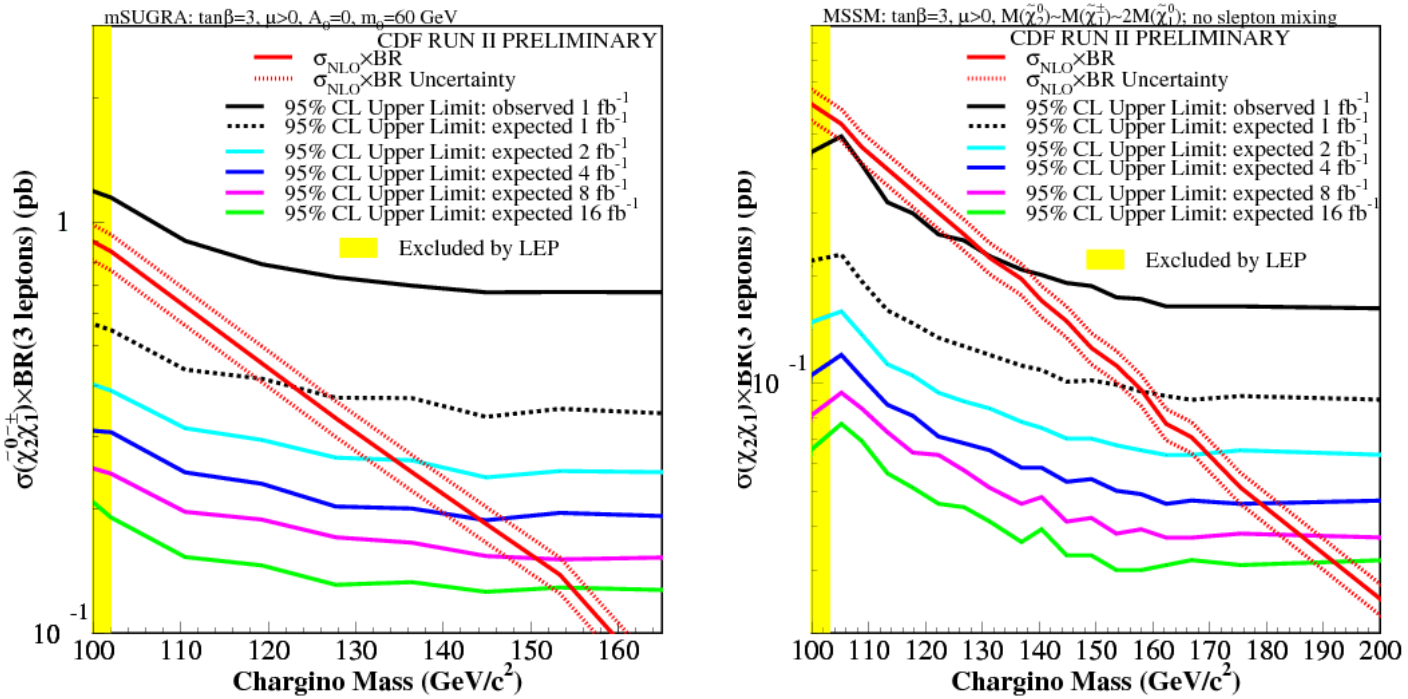
ITR(nom) : Isolated Track Rate : nominal (NTrk)
ITR(alt) : Isolated Track Rate : alternate parametrization ($SumE_T$ of jets)
Fake : lepton fake rate
Lumi: 6% not shown here.

Control regions uncertainties:
Lepton ID Scalefactor
Trigger Eff.

LO vs NLO cross-section is taken as 5% for DY samples.

Track isolation definition

- Track Isolation
  - CDF no tracks pt > 0.4 GeV in cone 0.4 around T (DeltaZ applied)
    - Or calorimeter E < 2 GeV
  - D0 hollow cone 0.1 to 0.4 sum pT must be < 1 GeV, calorimeter E < 3 GeV in hollow cone 0.2 to 0.4



Chargino and Neutralino: D0 model points

SIGNAL MONTE CARLO

Three reference points:

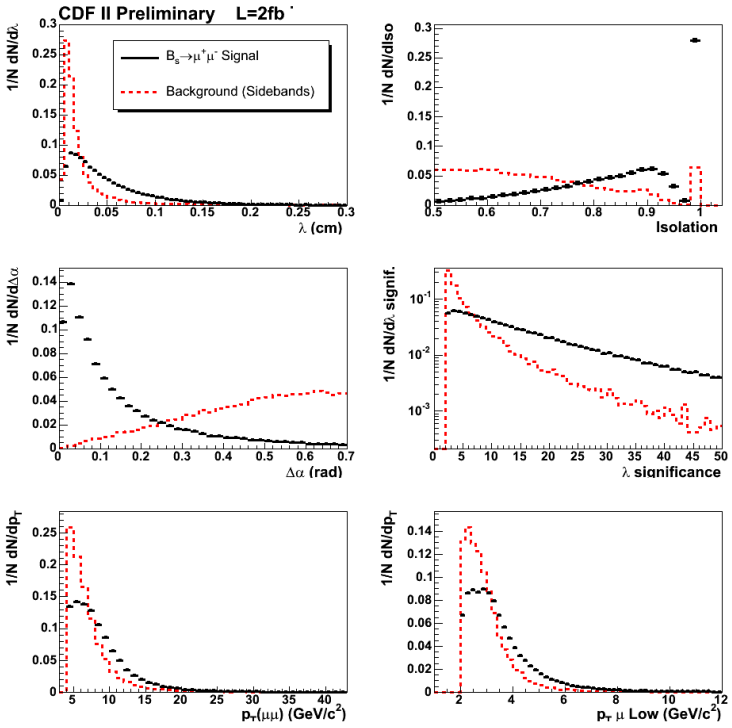
	HEAVY	MEDIUM	LIGHT
m0	121	98	88
m1/2	221	192	182
tan beta	3	3	3
mu	>0	>0	>0
A0	0	0	0
Char. mass	150	235	115
Neut2. mass	152	127	118
Neut1. mass	82	69	63
Slepton R.	153	129	119
sigma X Br	0.03	0.12	0.19

Mass of slepton just above the neutralino masses: $m_{\tilde{\ell}_R} \gtrsim m_{\tilde{\chi}_2^0}$

Also: $M(\tilde{\chi}_1^{\pm}) \approx M(\tilde{\chi}_2^0) \approx 2M(\tilde{\chi}_1^0)$

All masses in GeV

Bs @CDF



NN	ε_{NN}	B→hh Background	Total Background	Expected SM Signal
0.995-1.0	44%	0.039	3.5 ± 0.2	0.3 ± 0.1
0.95-0.995	23%	0.020	18.0 ± 0.7	0.15 ± 0.05
0.8-0.95	12%	0.011	49.5 ± 0.9	0.08 ± 0.03

Mass $m_{\mu\mu}$

2.5s window: s = 24MeV/c^2

Lifetime tau

$\lambda = ct$, $\sigma_{\lambda\ uncert}$ on lambda

Δa : $|f_B - f_{vtx}|$ in 3D between L and p mumu

Isolation: $p_{TB}/(\Sigma trk + p_{TB})$

$p_{T\mu\mu}$ and p_T second muon

Combine all but $m_{\mu\mu}$ in NN(New Element)

Removes 25% of the background

Set limits in using 3 NN bins and 5 mass bins (New Element)

Improves expected limit by 25%

- D0 Result: First 2fb^{-1} analysis!

$BF(B_s \to \mu^+\mu^-) < 9.3 \times 10^{-8}$ at 95% CL